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Recent Developments in Anaerobic Sludge Digestion in the United States and a View of the Future

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16. ABSTRACT

The presentation reviews current developments in sludge digestion that have been applied on a full scale in the United States and predicts future developments. Full scale experiments using thermophilic digestion at Los Angeles and at Chicago are described. Results of the evaluation of dual digestion (oxygen aerobic digestion followed by anaerobic digestion) at Hagerstown, Md., are presented. New developments, such as multiple digestion, developed by W. Torpey, are discussed. The impact of federal programs that encourage conservation of energy has greatly increased use of the excess methane produced in anaerobic digestion of sludge. Implications of the dependence created on this internally generated energy are presented. Research areas of high potential are also addressed.

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RECENT DEVELOPMENTS IN ANAEROBIC SLUDGE DIGESTION IN THE UNITED STATES AND A VIEW OF THE FUTURE

by

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INTRODUCTION

In the years of plentiful energy, anaerobic digestion in the United States was looked upon as a burdensome process that should be avoided if possible. There were trends toward processing raw sludge by incineration, thermal conditioning, and lime treatment. Aerobic digestion was touted as a far more robust process than anaerobic digestion, and was being used even in some large plants (e.g., Denver) despite its relatively high power cost.

The much-described energy "crunch" has changed these trends. Incineration has suffered twin blows: increased fuel cost and stricter air pollution requirements. Lime costs have risen because rising fuel costs have increased the cost of calcining limestone. Increased power costs have made aerobic digestion less attractive. Thermal conditioning is energy intensive unless the sludge is incinerated and a capital intensive incineration-heat recovery scheme is utilized. While these processes were becoming less attractive, anaerobic digestion was becoming more attractive, because it produces a valuable fuel. In the United States, there has been an upsurge of interest in anaerobic digestion based on this changed energy picture.

A powerful motivating force for greater interest in anaerobic digestion in the last few years has been the Innovative and Alternative Technology Program (I/A Program) that is part of the EPA's Municipal Construction Grants Program. Instead of the 75 percent funding that is normally contributed to approved construction projects by the federal government, an extra 10 percent increment is provided if the project is declared to be innovative or alternative technology. The specific definitions of "innovative" and "alternative" are operational and related to the regulations developed by the EPA to implement the Clean Water Act. An alternative technology must first be a <u>proven</u> method of treatment that reclaims water, productively recycles wastewater constituents, eliminates pollutant discharge, or conserves energy. If the process is also cost-effective, it qualifies as alternative technology. An innovative process is <u>not fully proven</u> and can qualify as innovative technology if it reduces either life cycle cost or net primary energy by specific amounts. Further details of the program are published elsewhere (1,2,3).

Since the I/A Program became active in October of 1978, it has impacted a great number of projects that involve sludge digestion. Projects that are alternative technology have outnumbered innovative projects. As will be discussed below, the lack of novelty implicit in alternative technology has not prevented the program from creating unexpected changes in the attitude toward sludge digestion in the United States.

New Developments

New developments in sludge digestion have come in the area of energy conservation, thermophilic digestion, two phase digestion, and combinations of aerobic and anaerobic digestion. This presentation is limited to developments carried through to the large pilot or full scale. Except in a few cases, the author is not so intimately acquainted with the projects that the person or persons who conceived or carried the burden of bringing creative ideas to fruition are known to him. References given are presented to give sources of information and regrettably may not always identify the people or organizations which most deserve acknowledgement. Acknowledgement must be made however to municipalities which frequently entered into development and demonstration programs without federal funding encouragement and to the framers of the Clean Water Act who who devised a successful means of motivating a conservative profession and industry to adopt new approaches.

Energy Conservation In the I/A program, anaerobic digestion projects qualify as alternative technology if they recover and productively utilize the methane generated. Consequently, for new plants being built or old plants being upgraded, it was inevitable that designers would give serious attention to including anaerobic digestion with energy recovery in the process train. A recent summary of energy conservation projects for sludge treatment or disposal which received the extra increment for I/A funding shows the following:

Type of Energy Recovery Projects	Projects
Codisposal of sludge and refuse	3
Anaerobic digestion	92
Self-sustaining incineration with energy recovery	15

The impact of the I/A provisions of EPA's Municipal Construction Program on numbers of plants using digesters is evident. Although the degree of innovation in most of these projects is not remarkable, they all have more or less elaborate ways of utilizing as much of the gas generated as possible. Most utilize the digester gas to drive reciprocating engines that either drive equipment directly or produce some of the electric power used in the plant. Cogeneration is an important feature of these plants. The waste heat from the engines is used to heat digesters or provide building heat. In another group of projects, the gas is used in gas turbines to produce electrical energy; heat is recovered from the exhaust gases by indirect heat exchangers and used for building heat and heating digesters. In most parts of the United States, office and laboratory space, even in sewage treatment plants, is air conditioned. The excess heat is frequently being used to drive absorption-chiller air conditioners, so there is a use for excess heat in both summer and winter. The City of Chicago has not opted for cogeneration but, at least in the summer, the effect is the same. They do not use engines or turbines but instead generate low pressure steam in large boilers. In the winter they have a high heat demand for digester and building heat. In the summer they use surplus heat to drive absorption chiller air conditioners. Since they would otherwise use purchased electricity to run air conditioners, they are practicing indirect cogeneration. Payout of the capital cost of the boilers is less than a year, and the boilers are easier to operate and maintain than gas engines.

Thermophilic Digestion. Thermophilic digestion is practiced in the United States only at the City of Los Angeles' Hyperion Plant (4,5). At the present time, only one of the city's digesters is being operated in this mode.

A recent publication indicates a strong interest by Chicago in thermophilic digestion (6). Experimentation was carried out on a 8900 m^3 digester (33.5 m diam. x 11 m) with an identical digester used as a mesophilic control. When operated at 14 days residence time, gas production per unit mass of volatile solids (VS) fed was higher (0.40 m^3/kg fed versus 0.32 m^3/kg) for the thermophilic digester (52 ^oC) than for the mesophilic digester (35 ^oC). However, the mesophilic digester produced more surplus gas (0.18 m^3/kg fed versus

0.09 m^3/kg) because its heating needs were lower. When the thermophilic digester was reduced to 7 days residence time and the mesophilic digester was kept at 14 days, the thermophilic digester continued to show superior performance.

Despite the evident superior performance of thermophilic digestion, Chicago has recently proceeded with plans to greatly expand its mesophilic digestion capacity. The primary reason for this choice was uncertainty about the odor of the thermophilically digested sludge. Odor was definitely different from mesophilically digested sludge, and was shown to be slightly more intense. Since Chicago's sludge is temporarily stored in lagoons near heavily traveled highways, it was thought prudent to remain "with the devil you know," since there was insufficient time to devise and carry out tests for acceptability before a decision had to be made.

Aerobic-anaerobic Digestion. A full-scale EPA-supported demonstration of aerobic-anaerobic digestion has been carried out in Hagerstown, Maryland, with considerable success. The process used is dual digestion, developed by Union Carbide Corporation, and now marketed in the United States by Lotepro Corporation (7). The process, which uses a one day aerobic digestion period using oxygen, followed by 8 days anaerobic digestion, is shown schematically in Figure 1. The only heat supplied is from biological oxidation. The dimensions shown in the figure are the dimensions of the Hagerstown installation. The anaerobic digester was badly matched in size and was operated at about half its volumetric capacity; residence time was reduced to a reasonable figure but was still too large to allow stressing of the anaerobic stage of the process.

The Hagerstown experiment demonstrated the workability of the aerobic digestion stage. At a residence time of 1.0 day and with relatively dilute feed sludge containing 2.75 weight percent volatile solids (VS), temperature rose from 20 °C to 50 °C in 8 days. After a severe shock load (an operator error) in which 78 m^3 of 20 °C sludge was charged to the 38 m^3 aerobic digester in 3 hours, temperature dropped to 34 °C but was brought back up to 50 °C in 23 hours by continuing oxygen feed but with no sludge input. The 16 kw input of the mixer accounted for 4 °C of this increase.

Performance data from the Hagerstown demonstration are presented in Table 1. The aerobic reactor achieved an average of 50 °C during the 4 month demonstration period. This is less than desired if disinfection of the sludge is to be achieved. After the demonstration period, weather became colder (see Table 1) but fortunately feed volatile solids increased. Temperatures were then easily maintained near 55 °C with no difficulty even at residence times of less than a day.

The full-scale demonstration in the deep aerobic reactor showed excellent conservation of energy. The following tabulation compares the relative heat flow terms:

Heat Input	Stirrer	: 0.225
	biological oxidation (calculated by difference)	: 0.775
		1.000
Heat Output	temperature increase of sludge	: 0.974
	calculated loss through wall and floor	: 0.020
	Loss in effluent gas (calculated from measured vent gas flow, temperature, and humidity)	: 0.006
		1.000

The low flow of vent gas was especially important in minimizing heat loss. The oxygen utilization efficiency is good, approximately 65 percent (at 32 rpm mixer speed). Much of the carbon dioxide that is formed does not replace oxygen in the gas phase but instead reacts with ammonia alkalinity, and remains in the aqueous phase. Consequently, vent gas flow is low with subsequent low evaporative cooling.

As noted earlier, the residence time in the anaerobic stage was excessive, and could not be properly stressed to observe any sensitivity to variables. Overall volatile solids reduction with the aerobic-anaerobic system were over 40 percent--about the same as the 40 day digestion practiced previously. The 41.9 °C temperature in the anaerobic digester is generally not considered an optimum temperature for anaerobic digestion; nevertheless, performance was adequate.

Temperature in the anaerobic digester depends almost entirely on the temperature of the sludge leaving the aerobic digester. The anaerobic digester will be slightly cooler than the aerobic digester by an amount that depends on the magnitude of heat losses.

At reasonable residence times and feed volatile solids content, temperature of the sludge leaving the aerobic digester can be precisely controlled at temperatures up to 55 °C by controlling oxygen flow rate. Temperatures in the anaerobic digester, which must be controlled more precisely than the aerobic digester temperature, can be maintained at the prescribed point by adjustments in oxygen flow rate to the aerobic digester. If it is desired to maintain a large temperature difference between the stages, for example, 35 °C in the anaerobic stage and 55 °C in the aerobic stage, heat must be removed, possibly by heat exchange between entering and leaving sludge streams at the aerobic digester.

The interest of the EPA in the system was directed in part to the ability of the system to produce a disinfected sludge. Table 2 shows elimination of viruses and Salmonella sp. from the aerobic reactor but the presence of Salmonella sp. in the anaerobic digester effluent. The higher densities of the indicator organisms and the presence of Salmonella sp. in the anaerobic effluent may be regrowth but could also be slower than expected washout of these organisms from this large digester. More definitive results will have to be obtained by long term observation in a system under better flow and temperature control than was maintained in the Hagerstown experiment.

The aerobic-anaerobic system is achieving a degree of commercial success in the United States. Two installations are nearing completion, one at Hendersonville, N. C. (0.18 m^3/sec wastewater flow) and the other at Lackawanna, N. Y. (0.20 m^3/sec). These are small plants equipped with oxygen activated sludge systems. Use of dual digestion is especially attractive for small plants that also use the oxygen activated sludge process. Aerobic reactor scale-up problems are minimized, and the digester gas can be used to power the PSA (pressure-swing adsorption) unit that supplies oxygen to the activated sludge plant as well as the aerobic digester.

Two-phase Digestion. Two phase digestion, in which sludge is digested in two vessels in series in order to separate hydrolysis or acid-phase digestion from the methanogenic phase of digestion will be applied on a large scale in Kansas City, Missouri. The facility will be constructed at the city's Blue River Treatment Plant and is expected to be in operation in December 1983 (9). The digester, which is presented schematically in Figure 2, is comprised of two coaxial vertical cylinders with a common roof, bottom, and a dividing wall. Sludge enters the interior compartment and overflows to the outer compartment. The inner compartment is mixed by a recirculating pump. The outer compartment is mixed by four mechanically powered draft tubes which direct the sludge downward with a tangential component to cause a general annular circulation. The inner and outer compartments can be maintained at different temperatures.

The digester design offers several advantages. Two stage digestion can be conducted at different temperatures. Mixing in the outer annulus should be more uniform than is the usual case for the large diameter shallow digesters in common use in the United States. The structural problems for the fixed cover should be much simpler than in a conventionally designed digester because the inner cylinder can be used for support. Fortunately, the installation has two identical digesters. Search for optimum operating conditions is more straightforward when two digesters can be run side by side, one at original conditons and the other at test conditions, and significant changes noted without the need to depend for evidence of change in comparisons with data obtained a few months past.

The Multiple Digestion Process. A recent innovative approach to digestion was demonstrated on a large scale by W. Torpey at New York City's Rockaway sewage treatment plant shortly after his retirement from active employment with the City of New York. This work has been described in a recent presentation (10). The process flow scheme used at Rockaway is presented in Figure 3. Raw and waste activated sludge are thickened (T-1), digested mesophilically (35 °C) in Digester D-1, and digested thermophilically (49 °C) in Digester D-2. The flow is then divided approximately in half. One half goes to the aerator; the other half is simultaneously elutriated and thickened (T-2), and withdrawn as product. Overflow streams from Thickeners T-1 and T-2 are returned to the primary influent.

Torpey et al. (10) reported results obtained during a four month operating period. Residence time in each digester during these tests has been calculated by this author to have been 13 days. Reduction in sludge volatile solids of 82 percent was achieved as compared to 56 percent reduction obtained in an equivalent period using conventional mesophilic conditions. Sludge volume discharged was reduced by an equivalent amount. The authors state that effluent quality did not deteriorate during the operating period. No data were obtained on change in oxygen requirement in the activated sludge process.

The Rockaway plant is still operating in the multiple digestion mode, although recirculation to the aerator has been discontinued pending installation of larger diameter piping. The new treatment plants under construction or in design at New York City (North River, Red Hook, Coney Island, and Owls Head) will be equipped to run in Torpey's multiple digestion mode. The North River plant is further along in construction than the rest--shells of the digesters have been erected, and funds have been obtained for construction of the solids handling facilities. Operation, however, may not actually be underway until 1990.

The North River plant is designed for a sewage flow of 0.644 $X10^6$ m^3/da. Design sludge flow for the mesophilic digester is 1,136 m^3/da of 6.3% solids sludge. Residence time in each digester is 20.8 days. There will be four mesophilic and four thermophilic digesters of equal size. Operation is similar to the flow scheme shown in Figure 3 except return activated sludge and return

digested sludge go directly to the aeration tanks--waste activated sludge is split off from the return sludge before return digested sludge mixes with return activated sludge.

There is active interest in Torpey's Multiple Digestion Process; for example, Dr. Karr at Atlanta is operating a small pilot plant to evaluate this approach in his facility.

Other New Developments. There has been substantial research and development activity in the Los Angeles area related to digestion, and decisions are being made as the plants in this area plan the upgrading of their secondary treatment and sludge handling facilities. The Sanitation Districts of Los Angeles County have done extensive experimentation in large pilot digesters with mesophilic and thermophilic digestion of waste activated sludge, and have evaluated the use of heat treatment before digestion to increase gas generation. It appears that they have decided to utilize mesophilic digestion only without such pretreatment, although waste activated sludge will be digested separately. Garrison et al. (11) have described the partially completed anaerobic digestion expansion underway at the 15 m^3/sec Joint Water Pollution Control Plant in Los Angeles. Six new circular digesters have been constructed and six others are under construction. The digesters are the largest diameter (38 m) and deepest cylindrical digesters that have been constructed in the United States. They have a capacity of 14,160 m^3, an outer wall depth of 11 m and a maximum liquid depth at the center of 15 m. The units are designed for 21 days detention time for waste activated sludge and 15 days for primary sludge.

The City of Los Angeles has taken a radical step (for the United States) and has installed four egg-shaped digesters at its Terminal Island plant. Volumetric capacity of each digester is 5,200 m^3. The digesters, which are 75 feet above ground (30 feet below ground), are an impressive landmark. The design of this high structure was especially challenging because of the special needs in Southern California for resistance to earthquakes.

Plans are well along for the City of Los Angeles' Hyperion plant expansion. Sludge will continue to be digested. A truly novel feature of the plant is the method of dewatering the sludge after it has been digested. The sludge will be centrifuged, dried by the Carver-Greenfield process, in which sludge is carried through multiple effect evaporators by a carrier oil, and separated from the oil by centrifugation and steam expression. The dried sludge will be combusted to produce steam. Steam and digester gas will drive turbines, producing electricity and process heat.

Impact of New Developments

The impact of the energy shortage and the new developments already on the scene will be substantial and continuing. The utilization of the energy produced by the digestion process to operate essential parts of the plant will now make digestion a very important process. It will not be possible to be minimally concerned about the performance of the digesters when (for example) the activated sludge process aeration air blowers are dependent on an adequate supply of digester gas for power. The entire level of digester operation and maintenance should rise with this need for optimized and reliable performance to avoid unbudgeted purchases of fuel or power.

The use of combination processes such as aerobic-anaerobic digestion or Torpey's multiple digestion process opens up a substantial number of possible approaches to sludge stabilization and production of digester gas that may reduce total processing costs. Heat treatment and wet oxidation processes can be combined with digestion processes in ways that reduce sludge volume and mass. There will be a major problem in trying to evaluate results unless improvements are so dramatic that comparisons are superfluous. Consider for example evaluating Torpey's multiple digestion process. For a proper comparison, two identical complete treatment systems equipped with dewatering facilities are needed to make the desired comparisons.

Trends and Needs in Research and Development

EPA's Program. EPA's sludge management program has not been active in the last few years in process development of anaerobic digestion, although it has made strong efforts to improve the state of knowledge of the effects of mesophilic and thermophilic digestion on pathogen reduction. The resurgence of anaerobic digestion makes it clear that a larger effort in this area is needed. Currently, two projects are being supported: an investigation of two-phase digestion by the Institute of Gas Technology in Chicago, and an investigation of the effect of enzymes on completeness and rate of digestion by Systech Corporation in Xenia, Ohio. An in-house program on the effect of post treatment of digested sludge by intermediate levels of wet oxidation will be undertaken in the near future.

Research and Development Needs. Recently, the Water Pollution Control Federation (WPCF) has published an analysis of research needs relating to wastewater treatment plant sludges (12). Research priorities were suggested for anaerobic digestion. First priority research needs given in the report are summarized below:

1. Studies leading to better mixing in digesters
2. Studies of acclimation to resistant of toxic substrates
3. A national survey of reliability in anaerobic digestion processes
4. Studies relating molecular structure and environmental conditions to anaerobic biodegradability
5. Kinetic studies to assess importance of substrate diffusion through gaseous films as a limiting mechanism in anaerobic digestion
6. Development of inhibiting detection techniques and process control procedures

Second and third priority lists are also given in the WPCF document.

The EPA recently sponsored a workshop (St. Louis, Oct. 1-2, 1982) at which advice was solicited from U. S. sludge digestion experts on fruitful research approaches. A very abbreviated list of recommendations is given below:

Basic Science (kinetics, microbiology). Investigate influence of nutrient deficiency in digestion, determine differences in kinetics of fixed film vs. suspended growth reactors.

Process Control. Define significance of hydrogen concentration in digester gas as a control technique or a danger signal, develop a stability index that indicates residual biodegradability of sludge (with no precise knowledge of prior history).

Process Design. Investigate effects of micro- and macro-mixing on digestion kinetics and relate energy to benefits, compare performance and economics of meso-, thermo-, and multiple digestion, define benefits of pre- and post-treatments (heat, enzymes, chemicals), determine limit of influent concentration on mixing, NH_3 toxicity, and performance.

Sludge Detoxification. Evaluate bacterial destruction as a function of processing scheme (e.g., processes in stages), nature of substrate, and degree of biodegradation of substrate.

Energy Recovery. Develop cost-effective procedures for recovering energy from liquid sludge, convert gas to energy via fuel cells or to a more storable feed by chemical means.

Education. Most digestion problems are "self-inflicted wounds." We do not apply what we already know. We must improve the competence of operating staffs and their knowledge of digestion.

There are many similarities in these two lists--five of the WPCF needs are duplicated in the EPA list. However, the most striking feature of the lists is that the projects all appear to be very important and well worth carrying out. This abundance of fruitful areas of research does not make it easy to choose the most fruitful area of research. A mission-oriented agency such as the EPA needs to factor in its own specific goals when it attempts to choose appropriate projects from this great abundance of worthwhile activities. For example, EPA's interest in minimizing capital costs of wastewater treatment plant construction might favor selection of projects that show potential for reducing digester size. In another area, its interest in health effects of sludge use on land might influence it to investigate the fundamental factors influencing elimination of bacterial pathogens during digestion. In this manner, the "universe" of good projects is reduced to a manageable few and selection becomes easier.

Closing Commentary

Recent years have brought a resurgence of interest in digestion in the United States. Federal funding programs have successfully encouraged construction of plants in which there is full utilization of sludge gas generated. Use of the sludge gas within the plant makes the entire operation dependent on good digestion; consequently, the entire level of sludge digestion will be upgraded as a result. New approaches to sludge digestion (multi stage or multiple digestion) are being made. Whether these approaches are the wave of the future is not known yet. Efforts must be made to evaluate these approaches on a bench scale now and on a full scale as soon as possible to determine whether the extra process complexity is worth the cost and effort. Until these techniques are shown to be effective at full scale facilities, no general movement to new approaches can be expected.

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TABLE 1

Summarized Performance of Dual Digestion System at Hagerstown, Maryland (1980)

	Demonstration Period	Post Demonstration Periods (Weekly Averages)			
	6/23 - 11/2	11/24	12/8	12/22	1/5/81
Temperature (°C)					
Feed	23.8	14.5	15.3	10.9	8.2
Aerobic effluent	50.5	55.3	53.6	55.6	55.4
Anaerobic effluent	41.7				
Ambient air	21.5	3.8	6.7	-3.2	-7.0
Residence Time (da.)					
Aerobic stage	1.38	0.97	0.73	0.68	0.53
Anaerobic stage	19.9				
Input Solids Concentration (%)					
Total solids	3.02	3.79			
Volatile solids	2.41	3.16	(...estimated > 3.16%...)		
pH					
Feed	6.0	5.7			
Aerobic effluent	7.1	7.2			
Anaerobic effluent	7.3	7.3			
Volatile solids removal (%)					
Aerobic stage	27.2	25.5			
Overall	41.9				

TABLE 2

Reductions in Bacterial and Viral Densities
by Dual Digestion

Biological Test or Species	Raw Feed (No./100 ml)	Aerobic Reactor* (No./100 ml.)	(log reduction)	Anaerobic Effluent** (No./100 ml)	(log reduction)
Total coliform	2.6×10^8	1.6×10^4	4.2	6.5×10^4	3.6
Fecal coliform	3.4×10^7	1.2×10^4	3.4	8.8×10^4	2.6
Fecal streptococcus	9.6×10^6	2.8×10^4	2.5	6.7×10^5	1.2
Salmonella sp.	30	< 0.3		60	
Virus	1000	< 2		< 2	

* median temp.: 52.4 °C, range: 51-61 °C, sampled near bottom of reactor

** median temp.: 42.5 °C, range: 40-42.6 °C

DUAL DIGESTION SYSTEM AT HAGERSTOWN

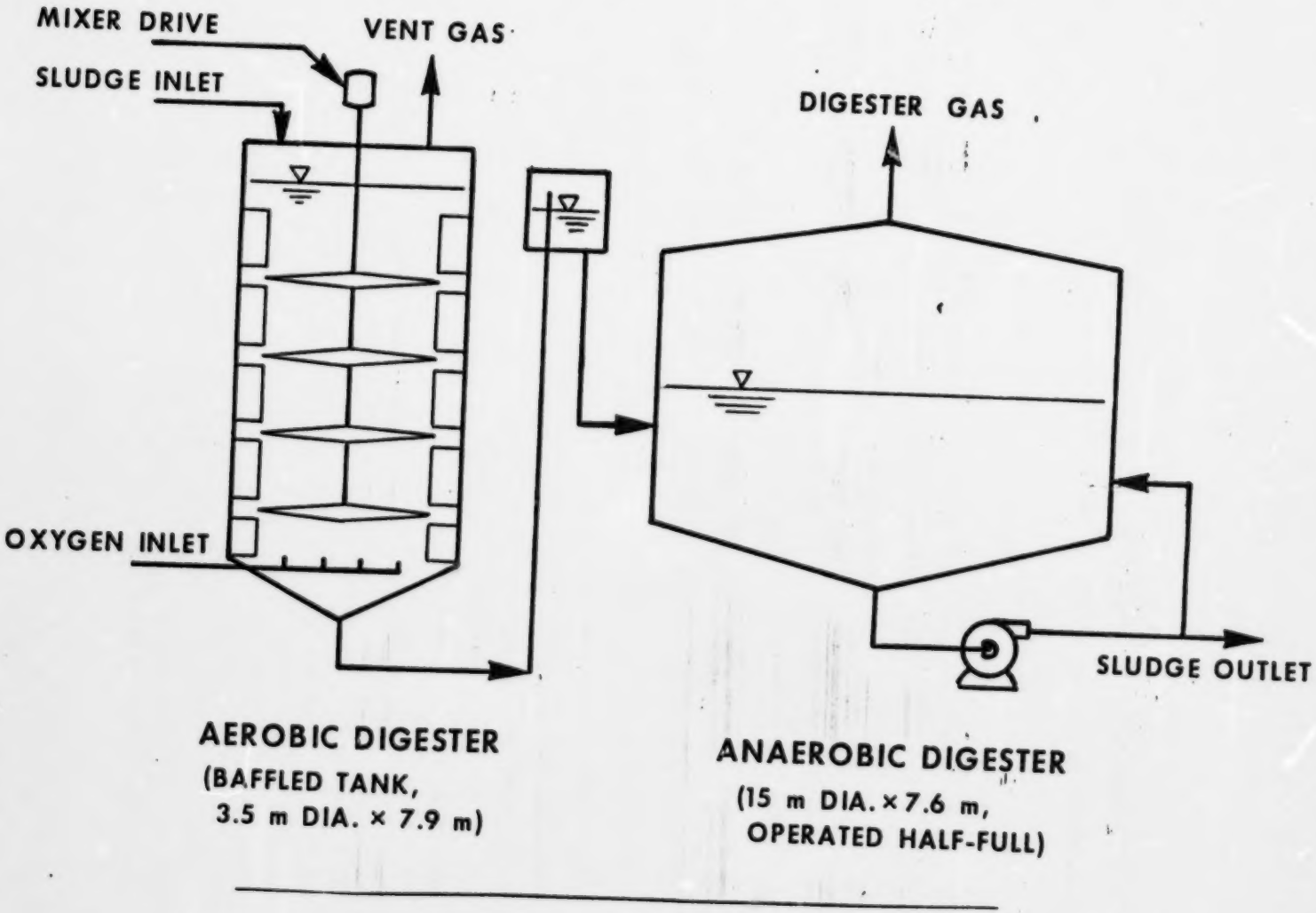
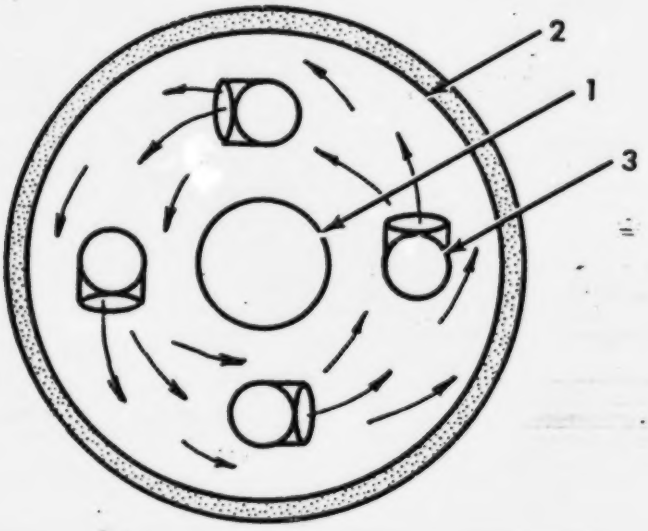
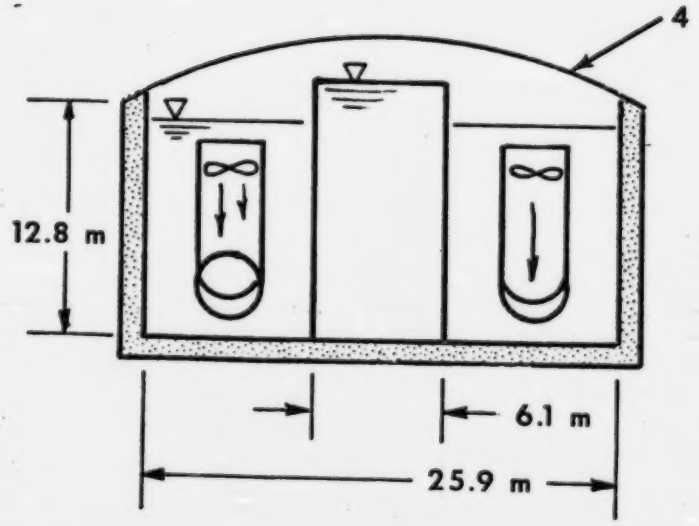


Fig. 1 : Dual Digestion at Hagerstown, Md.

TWO-PHASE DIGESTER, KANSAS CITY, MO

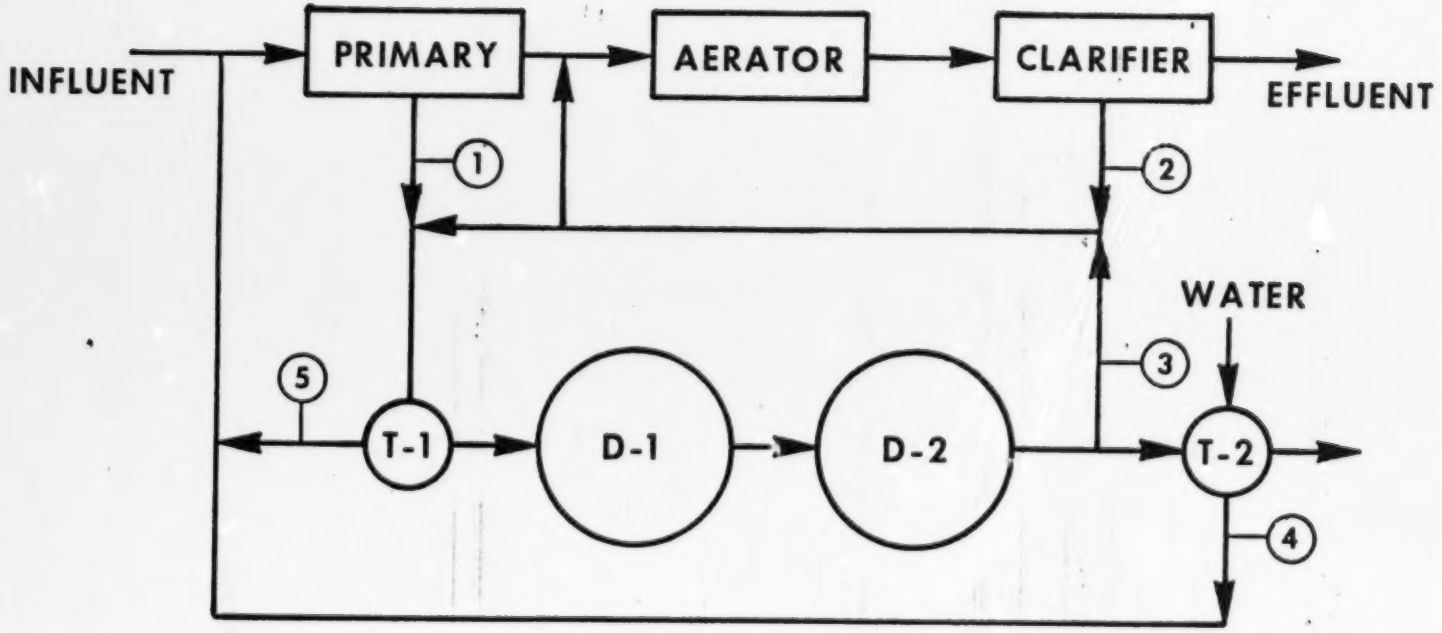




1. INNER COMPARTMENT ($374 m^3$)
2. OUTER COMPARTMENT ($6290 m^3$)
3. FOUR DRAFT TUBE MIXERS, BOTTOM OUTLET ORIENTED TO PRODUCE CIRCULATION IN ANNULUS
4. FIXED COVER

Fig. 2 : Two-phase Digester, Kansas City, Mo.

W. TORPEY'S MULTIPLE DIGESTION EXPERIMENT AT ROCKAWAY, N.Y.



T-1 THICKENER
D-1 DIGESTER (35°C)
D-2 DIGESTER (49°C)
T-2 THICKENER

1. PRIMARY SLUDGE
2. RETURN ACTIVATED SLUDGE
3. RECIRCULATED DIGESTED SLUDGE
4. ELUTRIATE
5. THICKENER OVERFLOW

Fig. 3 : W. Torpey's Multiple Digestion Experiment at Rockaway, N.Y.